# CHEMICAL INCIDENT SIMULATOR:
# A NEW APPROACH FOR DERIVING PASSIVE DEFENCE REQUIREMENTS

Marco J.G. Linders, Cornelis A. van Beest, Paul Brasser, Leon F.G. Geers, Gert van ‘t Hof, Ron A. Rumley-van Gurp, Reinier P. Sterkenburg, Simon C. van Swieten, Herman W. Zappey, Art R.T. Hin and Maarten S. Nieuwenhuizen

TNO – Prins Maurits Laboratory, P.O. Box 45, 2280 AA Rijswijk,The Netherlands,
nieuwenh@pml.tno.nl

## ABSTRACT

The ‘Chemical Incident Simulator’ (CIS) - a chain of linked simulation models - simulates the dispersion, detector responses, effects of protective equipment, and human toxicological responses for many realistic scenarios. Operational behaviour, like changes in ‘Dress State’ and typical reaction times are taken into account in the simulation.

All input and output data are stored in a database for easy access and retrieval. Analysis of individual scenario results and statistical analysis over all scenarios is possible. The casualty levels can be obtained for various health effect levels (eye effect, incapacitation, lethal) and protection levels (no protection, suit only, mask only, mask and suit, collective protection). This model thus largely eliminates the subjectivity involved in scenario studies, protective and detector equipment procurement.

## INTRODUCTION

Political and military tools are available to counter the threat of biological and chemical (BC) weapons and agents. Non-proliferation and disarmament are political and technical instruments that are more or less successful. In this respect, the Chemical Weapons Convention is a prime example of successful political measures in the chemical arena. This Convention prohibits the production, storage, handling and use of chemical weapons and all declared stockpiles have to be destroyed no later than April 2007. In spite of the successes of non-proliferation and disarmament, military tools are indispensable as well. Military defence measures, both active and passive, should aim at neutralising an imminent BC-threat. In the past decades, NATO’s strong airpower has almost completely eliminated BC challenges delivered by military aircraft. Currently, a lot of attention is focused on missile defence to annihilate ballistic missiles as means to deliver chemical and biological weapons.

Traditionally, passive defence has been the preferred way to counter the BC-threat, however. Passive defence encompasses the whole array of measures that are available to the soldier: detection and identification, physical protection, medical countermeasures and decontamination.

Events during the last decade have shown that weapons of mass destruction may be used by terrorists as well. As a result of possible amateuristic and opportunistic behaviour of terrorists, the threat spectrum has been stretched accordingly. The scale of the attacks as well as their locations (urban, indoors) have

# Report Documentation Page

*Form Approved*
*OMB No. 0704-0188*

Public reporting burden for the collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington VA 22202-4302. Respondents should be aware that notwithstanding any other provision of law, no person shall be subject to a penalty for failing to comply with a collection of information if it does not display a currently valid OMB control number.

| | | |
|---|---|---|
| 1. REPORT DATE<br>**15 NOV 2004** | 2. REPORT TYPE<br>**N/A** | 3. DATES COVERED<br>**-** |

| | |
|---|---|
| 4. TITLE AND SUBTITLE<br>**Chemical Incident Simulator: A New Approach For Deriving Passive Defence Requirements** | 5a. CONTRACT NUMBER<br>5b. GRANT NUMBER<br>5c. PROGRAM ELEMENT NUMBER |
| 6. AUTHOR(S) | 5d. PROJECT NUMBER<br>5e. TASK NUMBER<br>5f. WORK UNIT NUMBER |
| 7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)<br>**TNO Prins Maurits Laboratory, P.O. Box 45, 2280 AA Rijswijk,The Netherlands** | 8. PERFORMING ORGANIZATION REPORT NUMBER |
| 9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) | 10. SPONSOR/MONITOR’S ACRONYM(S)<br>11. SPONSOR/MONITOR’S REPORT NUMBER(S) |

12. DISTRIBUTION/AVAILABILITY STATEMENT
**Approved for public release, distribution unlimited**

13. SUPPLEMENTARY NOTES
**See also ADM001849, 2004 Scientific Conference on Chemical and Biological Defense Research. Held in Hunt Valley, Maryland on 15-17 November 2004 . , The original document contains color images.**

14. ABSTRACT

15. SUBJECT TERMS

| 16. SECURITY CLASSIFICATION OF: | | | 17. LIMITATION OF ABSTRACT | 18. NUMBER OF PAGES | 19a. NAME OF RESPONSIBLE PERSON |
|---|---|---|---|---|---|
| a. REPORT<br>**unclassified** | b. ABSTRACT<br>**unclassified** | c. THIS PAGE<br>**unclassified** | **UU** | **8** | |

**Standard Form 298 (Rev. 8-98)**
Prescribed by ANSI Std Z39-18

changed as well. Furthermore, NATO has changed its doctrine for the planning and execution of operations. Operations other than warfare are executed frequently, e.g. crisis response operations and peace enforcing, peace keeping and humanitarian operations. Finally, identifying passive defence measures has become a matter of concern for civil authorities as well.

Modelling and simulation are increasingly important instruments and these approaches have an enormous impact in the area of passive defence. Traditionally, the assessment of the chemical threat using the concept of challenge levels has been the primary focus. As the threat picture is changing, assessment of biological threats as well as threats exerted by (industrial) toxic compounds (including releases other than attack) have become important issues as well.

Threat assessment has been used as a starting point to define the requirements for a passive defence system. In the past, such requirements were determined on a more or less *ad hoc* basis. At the TNO Prins Maurits Laboratory we have started a scenario-based systemic approach to model the complete chain of passive defence measures, in order to derive challenge levels and casualty levels. This enables us to study the effects of passive defence requirements upon these levels, thus improving the selection process.

## CHEMICAL INCIDENT SIMULATOR

The Chemical Incident Simulator, CIS, simulates events that encompass the passive defence against chemical warfare agents. The model starts in 'release, transport and dispersion' mode, where the agent release in an incident scenario is simulated. In this mode the model generates concentration-time exposure profiles for the detectors, mask, suit, filters and people present in the scenario. In addition, challenge levels to the whole target are calculated. In the next step the model is in detection mode; as soon as the release of a chemical agent is detected, an alarm is generated. These detection alarms and the exposure profiles are input for the next mode, where the skin and respiratory protection models are triggered. These models calculate the amount of protection offered by the protective material. This results in exposure profiles for lung, eye and skin to liquid, vapour and aerosols. In the final mode the toxic-effects model translates the exposure profiles into casualty probabilities for the personnel.

Scenarios, i.e. attacks or incidents, are needed as input for the model. Over the years an extensive number of scenarios has been collected. For easy retrieval of scenarios a database has been built. The scenario takes into account all relevant factors necessary to calculate challenge levels, i.e. target data, weapon characteristics, chemical agent properties and meteorological effects. Furthermore, different NBC-alert states (Mission Oriented Protective Posture – MOPP) can be selected. These states range from 'low', meaning no protective clothing or mask is worn, to 'high', meaning the soldier is completely protected. Each alert status is characterized by time intervals that define how long it takes before the mask and suit are worn, thus offering their respective protection. The resulting challenge levels, dosage fields and deposition fields, are stored in the database as well.

In the future, the system will ideally provide an analysis tool to support planning and decision making. The system will support stand-alone operation in an analytical mode as well as interfacing with an integrated warning and reporting network to provide real-time analysis capability. Ideally, the system should also be capable of interfacing with other models that simulate the effects of blast, fragmentation, fire, nuclear events and combinations thereof. Finally, it should be noted that the systemic approach could also play a role in defining research policies, as it will be capable of pointing out relative weaknesses in the passive defence system which need improvement.

### Release, transport and diffusion

For release, transport and diffusion the simulation program RAP2000 is used. The engine of RAP2000 consists of a series of models that predict physical quantities like concentration and surface deposition as function of time and location, given a chemical or biological release scenario. Together these models are indicated as RAP, the Risk Analysis Package. The latest version RAP2000 is capable of: 1) easily creating many (variations of) scenarios; 2) simulating the individual scenarios; 3) storing and updating the scenarios and results in a database; and 4) analysing the scenario results. The results of model calculations can be analysed individually (per scenario) or statistically (using any desired subset of the scenarios database).

A major premise of RAP is that every chemical or biological attack, including line shaped spray releases, can be split up in single sources. A single source is defined as a cloud of vapour and liquid drops with a three dimensional Gaussian mass distribution. A single source itself is split up in an initial vapour puff and a number of puffs containing droplets with the same size. These initial puffs have the same geometry as their ancestor single source. Within RAP movement and dispersion of puffs is handled analytically for the major part.

RAP simulations are thus based on a concept with a clear hierarchy. The lowest level is the puff. Vapour and droplet puffs make up a single source and finally one or more single sources define a scenario (see Figure 1). Single sources are allowed to appear at different times and locations in the scenario. After generation of the single source and its puffs, drops start to fall and evaporate, generating additional vapour. At the same time the drops are transported by atmospheric motion. Finally, drops might reach the surface. The corresponding puffs then become “lying” puffs and start to generate secondary vapour. For all these processes RAP contains physical models. Apart from the release, transport and diffusion models RAP also contains a module that handles blast and fragment dispersion associated with artillery shells filled with chemical warfare agents.

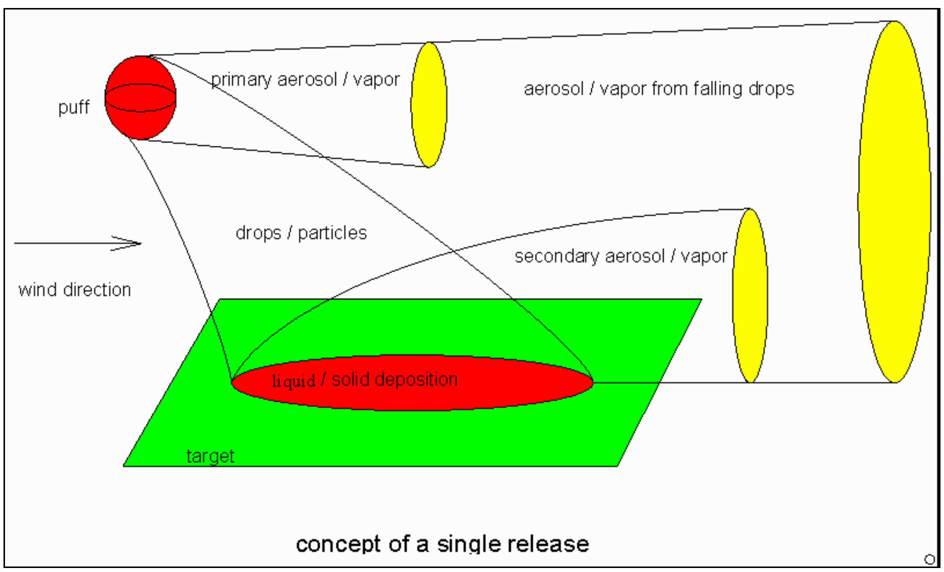


Figure1: Release, evaporation and dispersion models of liquid and vapour in RAP.

## Detector model

The detector model is capable of simulating both vapour and liquid detection systems. So far, about a dozen different detector systems are available. The detector model input signal consists of: i) a time concentration profile, ii) the identity of the chemical warfare agent (HD, GB, VX or L) and iii) the relative air humidity (RH < 80% or RH > 80%).

For vapour detection there are three aspects that are modelled: sensitivity, response time, and regeneration. The sensitivity determines at which concentration level the detector will respond. The theoretical detector output (alarm or no alarm) is calculated by comparing the input data (concentration, relative humidity) with empirical detector display outputs, obtained during laboratory experiments. The response time determines how long it takes before the detector shows the response. The regeneration time determines how long it takes before the detector can do a new measurement.

The liquid detector model simulates the behaviour of detection papers, which are in operational use by many Defence forces. It simulates whether or not a paper will show a visible coloration, depending on deposition density and droplet sizes.

The theoretical detector display outputs are corrected for operational detector procedures and residual contamination. The output signal is used in both the respiratory and skin protection models to increase the protection level when the signal switches to “alarm”, and to decrease the protection level when it switches to “clear”. The complete process of retrieval of input signal, performance of calculations and the generation of output signal needs only a few seconds.

**Skin protection model**

The skin protection model, or suit model, calculates the concentration of warfare agents, which penetrates the NBC-clothing. This concentration is determined by the state of protection: when protective clothing is worn, this concentration is determined by the breakthrough of agents through the suit, and when no protective clothing is worn, the skin concentration equals the concentration in the surroundings of the soldier. The vapour is adsorbed on the carbon, which is present in the NBC-protective clothing. Due to the characteristics of the clothing material, there will always be a certain breakthrough concentration of vapour. The breakthrough concentration is calculated by the model on the basis of the type of NBC-protective clothing material, the outside concentration, the temperature, the wind speed, the time of exposure, the type of vapour etc. Next to vapour contamination, the suit model also includes a basic liquid drop model. When liquid drops hit the clothing material, they will start to evaporate, and this vapour can also penetrate the clothing. Currently, liquid breakthrough is not yet covered by the model because of the complexity of this matter. Several models for liquid breakthrough are being tested at the moment. The liquid drop model is being extended to take into account the effects of wicking and wetting of the material by liquid. All of the aforementioned processes together result in a breakthrough concentration as a function of time.

**Respiratory protection model**

The respiratory protection model, or mask model, consists of two parts: a carbon filter model and a mask leakage model. The carbon filter model predicts the vapour breakthrough through the filter as a function of time. The model is valid for the adsorption of a vast number of physisorbed organic contaminants. Climatic aspects like temperature and humidity are important parameters in this respect. Different – but constant – scenario temperatures are possible, provided that all parameters are known or can be estimated at the temperature of interest. Humidity has not yet been incorporated. During actual use of a gas mask the flow through the filter is not constant. A breathing cycle will be incorporated in the model by applying a sine wave pattern, which closely resembles the actual breathing pattern. Furthermore, the breathing volume must be included as well, as it depends on the status of the soldier: breathing is more intense during work than in a state of rest.

The leakage model is deduced from protection factor measurements of people wearing gas masks in the field. The leakage is expressed as a distribution of protection factors as it varies quite a lot over a population of people. The final vapour concentration that a soldier inhales and to which the eyes are exposed, is a fraction-based mean of the breakthrough through the filter and of the leakage at the sides of the mask.

### Toxic effects model

The toxic effects model uses concentration-time profiles from the respiratory and skin protection models as input to estimate casualty probabilities. Two approaches are available: a simple linear dose-effect model as incorporated in RAP and a more elaborate non-linear response model, based on the Toxic Load approach. The latter provides a better description of toxic effects for agents that show significant deviations of simple Haber's law behaviour (i.e. toxic responses only depend on the concentration-time product and not on each quantity separately).

Toxic effects of expositions are calculated for a variety of exposures and effect combinations, assuming a probabilistic dose-effect relationship. Lethal and incapacitating responses (e.g. respiratory effects, topical skin effects or incapacitating eye effects) of varying degrees of severity are addressed. The model also distinguishes between effects resulting from vapour exposure and from exposures to liquid droplets. These primary effect probabilities are subsequently combined to afford overall casualty probabilities for lethality, severe incapacitation and incapacitation due to topical eye effects.

The model is also capable of addressing the effects of various medical countermeasure protocols upon casualty flows, e.g. when chemoprophylaxis and/or specific therapeuticals for intoxications are available. At present, this aspect is not parameterized properly and therefore is available only as a prototype to demonstrate proof of principle.

The toxic effects model relies on many consensus parameters that describe toxicological and pharmacological effects. These consensus parameters are the result of an in-house review of available toxicological data. Other parameters (e.g. those derived from NATO study groups) may, however, be used when necessary or desired.

Future developments will include the development of consensus parameters that describe realistic medical countermeasure effects. An important new feature will consist in the assessment of casualty flow onset times, by calculating the dose-build-up and the resulting development of casualty probabilities in time.

## RESULTS AND DISCUSSION

The Chemical Incident Simulator simulates the dispersion of chemical warfare agents, detector responses, the effects of protective equipment, and the human toxicological responses for large numbers of scenarios. The possibilities and potentials offered by the Chemical Incident Simulator are illustrated best with an example.

The calculations start by defining the scenarios: incident properties such as target, terrain, climate, weapons, agent etc.; personnel deployments – type of protection available (mask, suit); detector deployments – single detector, array of detectors, location; and NBC-alert state. Subsequently, the 'agent release and transport' in the scenario is calculated, which results in concentration-time profiles at the locations of detectors and personnel. To illustrate the concept, the impact of 740 small submunitions from a TBM, releasing the nerve agent sarin, is used. Figure 2 depicts the liquid deposition density as a result of the attack.

The locations of the detectors, an array of eight, are shown in Figure 2 as well. The detector model generates an alarm-time profile when a chemical agent is detected. As the concentration exceeds a given threshold, the detector status changes from "clear" to "alarm". After the concentration drops below the threshold, the status reverses to "clear" again. In case of multiple detectors in the field, an overall alarm profile is generated, which is clearly shown in Figure 3. Eight alarm profiles plus the overall profile are shown (scaled between 0 and 1), each corresponding to the local concentration profile. As soon as any of the individual detector outputs changes to "alarm", the overall output of the detector model is "alarm" as well.

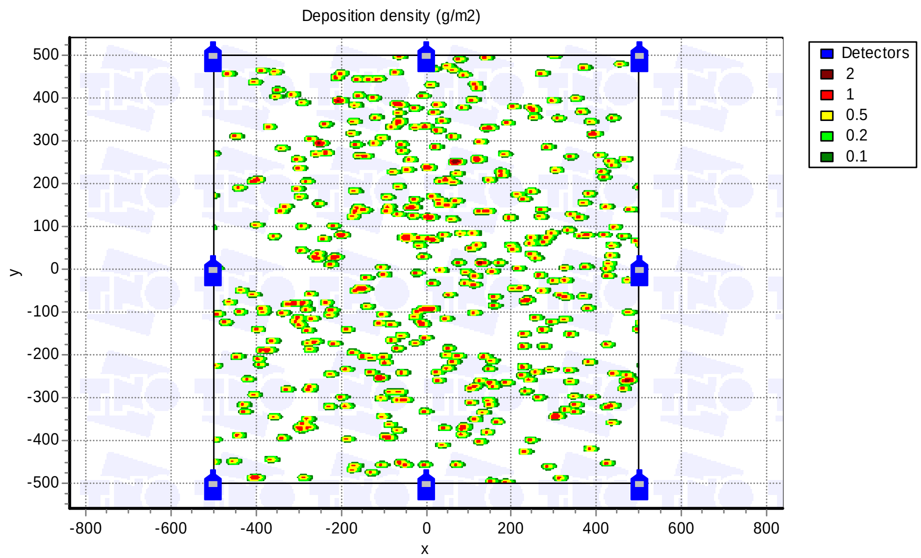


Figure 2: Liquid deposition density of sarin on the target area.

Based on the concentration-time and alarm-time profiles, the skin and respiratory protection models calculate exposure profiles, using the characteristics of the provided protective equipment. The alarm is set almost instantaneously, see Figure 3. Therefore, the mask is worn immediately, only taking into account 15 seconds delay – the time it takes to put the mask on. Figure 4 shows the influence of wearing respiratory protection on the exposure to sarin. Clearly, the carbon filter provides sufficient protection in this case. However, in practice always leakage occurs to some extent through the mask. The figure shows two exposure profiles with different protection factors. As a consequence, the dosage that one inhales, or to which the eyes are exposed, varies with the actual protection.

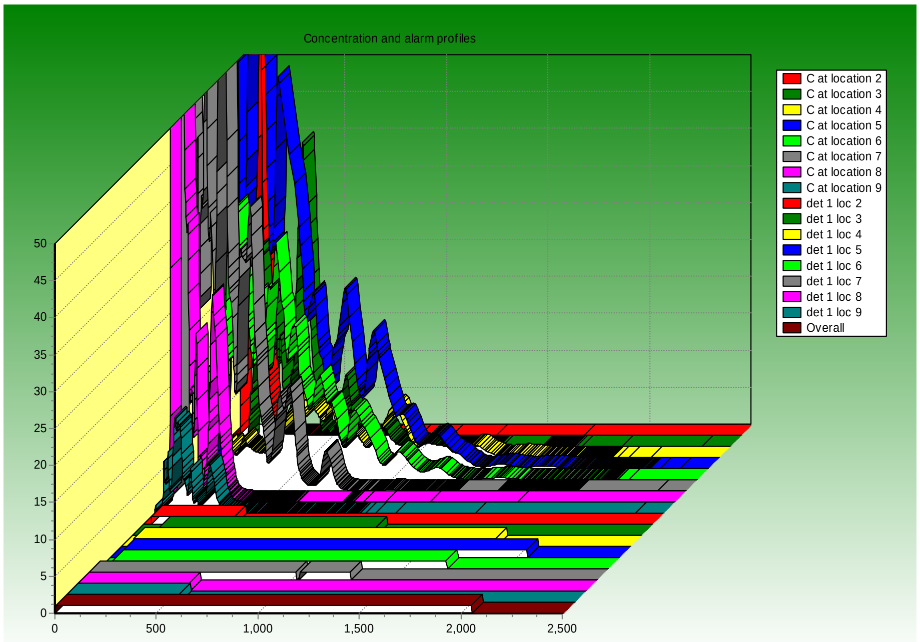


Figure 3: Concentration-time and alarm-time profiles of 8detectors and the overall alarm profile.

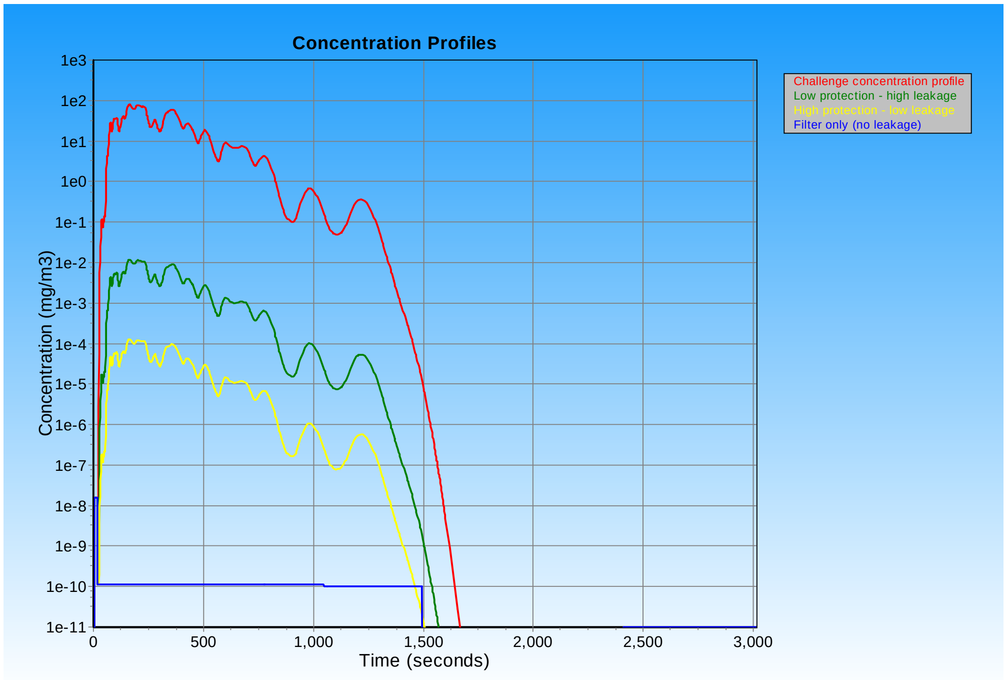


Figure 4: Influence of wearing respiratory protection on the exposure to sarin.

The toxic effects model translates the exposure profiles into casualty probabilities for the personnel, assuming a probabilistic dose-effect relationship. The casualty levels and spectra can be obtained for various type of health effects, e.g. eye effects, inhalation, percutane, subdivided in two levels (incapacitating and lethal), and various protection levels, e.g. no protection, suit only, mask only, mask and suit, and collective protection. Table 1 gives a typical result for one scenario. In case no protection is used, 63% of the population dies due to inhalation of sarin and 25% dies due to percutaneous exposure. Clearly, when both mask and suit are worn, the casualty levels are dropping drastically.

TABLE 1: Affected percentage of the population for various effects and protection levels.

| Toxicity | | No protection | Mask only | Suit only | Mask and Suit |
|---|---|---|---|---|---|
| Eye effects | Incapacitating | 81 | 21 | 81 | 21 |
| Inhalation | Lethal | 63 | 4 | 63 | 4 |
| | Incapacitating | 76 | 11 | 76 | 11 |
| Percutaneous | Lethal | 25 | 25 | 2 | 2 |
| | Incapacitating | 45 | 45 | 13 | 13 |

All input parameters, scenario definitions and results are stored in a database for easy access and retrieval. Analysis of individual scenario results and statistical analysis over all scenarios (or any subset) is possible. Typical individual scenario results are deposition, dosage and casualty level on the attacked target. Typical statistical analysis results are dosage and deposition threat spectra, and casualty spectra. Figure 5 presents a typical example of a dosage spectrum. It shows the frequencies of occurrence that a certain dosage level is exceeded in 5% of the target area for three agents.

Thus, the Chemical Incident Simulation model largely eliminates the subjectivity involved in scenario studies, and procurement of protective and detector equipment.

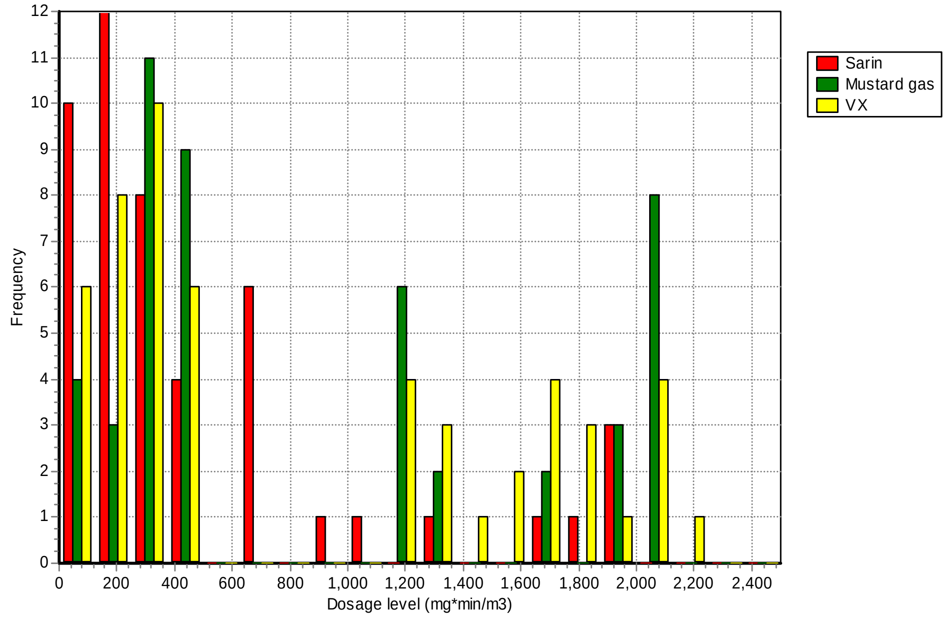


Figure 5: Frequencies of dosages that are exceeded in 5% of the target area.

## CONCLUSION

The example given above shows that CIS can simulate the effect of the complete passive defence chain in a consistent way. The strength of CIS is that it can simulate this effect for a huge number of different situations and thus is able to establish passive defence requirements in a systematic way. The proof of principle for simulating the complete protection chain has been given. Extensive work has to be done to refine this approach, so that CIS can be an effective tool to set requirements for real life situations.

This paper deals with the current status of this potentially very powerful tool and shows characteristics and capabilities, and some typical results. In the near future, while the CIS module will mature, it is foreseen that a so-called CIS user group will be initiated, which NATO countries can join.